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Abstract: OBJECTIVE To quantify intrapelvic surface symmetry in reference to a pre-shaped suprapectineal acetabular implant. METHODS In this cross-sectional study, an anatomically pre-shaped acetabular fracture implant was fitted on 3D surface models of 516 pelvises from a pre-existing bone database using a software tool for automated implant fitting (SOMA, Stryker Orthopaedic Modeling and Analytics) of a CAD model of the implant. The distances between bone and the reference implant were measured at 2310 reference points for each hemipelvis. RESULTS The average distance between the left hemipelvis and the plate was 1.98 mm (median, 10% percentile: 1.45, 90% percentile: 2.78) and 2.0 mm (median, 10% percentile: 1.45, 90% percentile: 2.92) between the right hemipelvis and the plate. There was no significant difference between the two hemipelvises (medianabsolute pairwise delta: 0.25mm; 10% percentile: 0.04, 90% percentile: 0.82; Wilcoxon, p = 0.064). CONCLUSION With regard to the periacetabular surface of the inner pelvis, the pelvis can be considered sufficiently symmetric for using the mirrored contralateral hemipelvis as a template for patient-specific implants in acetabular fracture fixation.

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Symmetry matching of the medial acetabular surface – A quantitative analysis in view of patient specific implants

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Abstract

Objective: To quantify intrapelvic surface symmetry in reference to a pre-shaped suprapectineal acetabular implant.

Methods: In this cross-sectional study, an anatomically pre-shaped acetabular fracture implant was fitted on 3D surface models of 516 pelvises from a pre-existing bone database using a software tool for automated implant fitting (SOMA, Stryker Orthopaedic Modeling and Analytics) of a CAD model of the implant. The distances between bone and the reference implant were measured at 2310 reference points for each hemipelvis.

Results: The average distance between the left hemipelvis and the plate was 1.98 mm (median, 10% percentile: 1.45, 90% percentile: 2.78) and 2.0 mm (median, 10% percentile: 1.45, 90% percentile: 2.92) between the right hemipelvis and the plate. There was no significant difference between the two hemipelvises (medianabsolute pairwise delta: 0.25mm; 10% percentile: 0.04, 90% percentile: 0.82; Wilcoxon, p = 0.064).

Conclusion: With regard to the periacetabular surface of the inner pelvis, the pelvis can be considered sufficiently symmetric for using the mirrored contralateral hemipelvis as a template for patient-specific implants in acetabular fracture fixation.

Keywords: acetabulum; acetabular fracture; pelvis; pelvic fracture; patient specific implants.

Introduction

The quality of reduction is one of the key prognostic factors for long-term outcome in patients with acetabular fractures.[1–3]

Along with the increasing use of anterior approaches, indirect restoration of the articular surface represents a particular challenge. [4] Therefore, the intraoperative quality control of pelvic reduction has to be as perfect as possible.[1] Kistler and Sagi reliably documented that anterior approaches are safe and even allow for posterior indirect fracture fixation but pointed out that precise visualization represents a key step in achieving anatomic intraoperative reduction. [5]

Especially in the presence of comminution, excellent reduction is difficult to achieve due to missing osseous landmarks and references.[1] Hence, the learning curve in acetabular surgery is known to be long and flat.[6]

Anatomically pre-shaped suprapectineal plates have been shown to be helpful in facilitating indirect reduction of acetabular fractures through an anterior approach. [7] However, even these pre-shaped implants represent an average of many templates that approximates the individual patient's anatomy. This is especially important as they are not foreseen to be bent due to the 90° configuration of the buttress shield, which was designed to increase stiffness. Therefore, their concept is to use the plate as a reduction tool rather than bending the plate after open reduction has been performed.[8]

To help improve intraoperative reduction, the idea of patient specific implants has been developed.[9] These implants are thought to offer the advantage that once the implant fits well to the intrapelvic or suprapectineal osseous surface, the surgeon can better trust in the quality of their reduction inside the joint. Creating a patient specific implant requires a template of an intact acetabulum. For this, virtual reduction of fracture,or the use of a 3D-printed model have been proposed . [9, 10].

Currently, the use of the mirrored noninjured hemipelvis as a template appears to provide the best option to generate such a template

However, this method implies a symmetry of high degree. In view of the small gaps and steps that can lead to posttraumatic arthritis of the hip, the differences between the two contralateral sides should range within a few millimeters.[3]

To our knowledge, this factor has not been addressed so far. Therefore, it was the aim of this study to quantify intrapelvic surface symmetry in reference to a pre-shaped suprapectineal acetabular implant.

Methods

A preexisting data base was used for assessment (SOMA, Stryker Orthopaedic Modeling and Analytics, Stryker Trauma GmbH, Schoenkirchen, Germany). It summarizes data of 516 human pelvic cadavers, listed as two and 3 D templates. As this CT database contains data from complete human pelvises, it is a viable option to mimic intraoperative templating without the risk of being affected by specific intraoperative views.

An anatomically pre-shaped acetabular fracture implant (PRO Suprapectineal Plate, Stryker, Selzach) was used as a virtual reference in 3D pelvis datasets and distances between bone and the corresponding implant were measured for each hemipelvis. The comparison of these distances of bone to a volumetric reference allowed to assess the degree of symmetry of each pelvis.

We used an implant fitting tool of a 3D modelling and analytics environment (SOMA, Stryker Orthopaedic Modeling and Analytics, developed in collaboration between the Clinic of Orthopaedics and Sports Orthopaedics of the Technical University Munich and Stryker Trauma GmbH, Schoenkirchen, Germany) a virtual CAD model of the reference implant was automatically fitted on the medial acetabular surface of 3D surface models of 516 pelvises from the existing SOMA database [11]. In contrast to other potential references (e.g. a pre-defined line or landmark) a virtual pre-shaped suprapectineal plate was thought to better respect the complex surface geometry of the pelvis. This technique has been used successfully for the software-based development and verification of femoral stems in total hip arthroplasty.[12]For each pelvis, a right-sided anatomical acetabular plate was virtually fitted to a 3D surface model of the right hemipelvis and a left-sided anatomical acetabular plate was fitted to a model of the left hemipelvis.

All 3D surface models were created based on CT scans from the SOMA database acquired exclusively for medical indications: polytrauma (20%), CT angiography (70%), and others (10%). Pelvises with fractures, pelvic ring deformity, hip dysplasia, and hardware in situ

were excluded. The median age was 64.5 years with an interquartile range (IQR) of 25 years. 39% of the datasets were female, 61% were male.

Endpoints

Distances between the hemipelvis surface model and the reference implant were measured for every mm² of the plate (in total 2310 reference points) for each hemipelvis. These measures were averaged for each hemipelvis. Primary endpoint was the pairwise delta that was defined as the median absolute difference between the right and left average bone-to-implant distances. Secondary endpoint were region-specific distances between implant and bone as seen in 1) the anterior region of the implant around the pubic rami, 2) the periacetabular interval, and 3) the most posterior region around the sacro-iliac area

Statistical analysis

Statistical analysis was done by the use of SPSS for windows 23.0 (SPSS, Chicago, Illinois, USA). Data are presented as medians with percentiles. To assess differences in medians between the two groups, a Wilcoxon Signed Ranks Test was used. The level of statistical significance was set at $p < 0.05$.

Results

Fitting of the reference implant was achieved in all 516 pelvises.

The median distance between the left hemipelvis and the plate was 1.98 mm (10% percentile: 1.45, 90% percentile: 2.78) while it was 2.0 mm (median, 10% percentile: 1.45, 90% percentile: 2.92) between the right hemipelvis and the plate. The median absolute difference between the given contralateral hemipelvises was 0.25mm (10% percentile: 0.04, 90% percentile: 0.82; Wilcoxon, $p = 0.064$; Figure 2, Table 1). In relation to the reference

implant, the highest bone-to-implant distances were found at the anterior region of the implant around the pubic rami (Figure 4), followed by the most posterior region around the sacro-iliac area. In a few cases, the distance between certain regions of the reference plate and the bone surface was more than 10 mm. At the periacetabular interval of the reference plate, however, the mean distances were below 2 mm.

Table 1 Implant-to-bone distances

		Percentiles						
		5	**10**	**25**	**50**	**75**	**90**	**95**
Mean distance [mm]	right	1.32	1.45	1.68	2.00	2.42	2.92	3.33
	left	1.33	1.45	1.64	1.98	2.34	2.78	3.12
Pairwise delta [mm]		0.02	0.04	0.11	0.25	0.47	0.82	1.03

"Mean distance" represents the average distance between reference plate and bone surface. "Pairwise delta" represents the median absolute difference between the right and left mean distances

Discussion

Accuracy of intraoperative reduction represents an important goal in acetabular surgery. [13] Failure to achieve a congruent joint surface is known to represent a risk factor for posttraumatic arthritis and imaging techniques play a major role. Recently, Maini et al pointed out that virtual planning may be helful in defining a role for improvment in visualization. [14] Likewise, Banerjee and Starr reported that CT based software represents a safe guide for both, anterior and posterior column fixation. [15]

The current study aimed to quantify intrapelvic surface symmetry in reference to a pre-shaped suprapectineal acetabular implant and to detect areas of high variability where patient specific bending may help to improve fitting.

Our main results are as follows:

1. A high degree of symmetry between both hemipelvises was found in direct comparison of the hemipelvises.
2. While in general, the fit of the precontoured plate was excellent with low inter-individual variance especially in the periacetabular region, we observed some deviations in the anterior region of the implant around the pubic rami. This could mean that these plates may need additional bending in the distal region in some patients.

However, primary aim of this study was to investigate whether the contralateral inner hemipelvises of an individual show a symmetric periacetabular surface. In the vast majority of the 516 pelvises, the maximum differences in bone-to-implant surface between the right and lefts side were less than 1 mm. Hence, the surfaces of the right and left periacetabular region can be considered highly and sufficiently symmetric in order to serve as a template for reconstruction in case of a contralateral acetabular fracture. Due to the high degree of symmetry, patient-specific implants shaped on the contralateral hemipelvis are unlikely to induce gaps or steps when reducing a fracture over the plate.

Pre-shaped anatomical plates were recently introduced, that fit to the average intrapelvic surface of multiple individuals.[7] However, as seen in this study, the inter-individual variability of the intrapelvic surface topography is high. Hence, surgeons can never be sure that their patient fits the average. Mirroring of the contralateral hemipelvis was suggested and has been described for patient-specific implants in acetabular fractures.[16] So far, symmetry of the two hemipelvises has been investigated only in terms of distances and angulations.[17] A direct comparison of the periacetabular cortical surface had been missing. This work provides basic data on surface symmetry of the periacetabular inner pelvis and supports the use of the mirrored contralateral hemipelvis as a template as previously described. [9]

Our study has both, strengths and limitations. Strengths include the use of a standardized high volume data base with high accuracy and no degenerative induced limitations and a standardized plate application through virtual placement.

Obviously, mirroring the contralateral hemipelvis will not be useful in all individuals. Patients with severe deformities of the axial skeleton as seen in adolescent idiopathic scoliosis are likely to have different curvatures of their right and left hip bones.[18]

The measurements of this study are based on CT scans and segmentation was done for using a threshold for bone. Thus, the results of this study did not take into account any asymmetries of the soft tissues between implant and bone. It seems likely that the thicknesses of the periosteum is the same on both hemipelvises. However, an acetabular injury and a subperiosteal approach to the fracture can produce differences especially in the periacetabular region in surface geometry not foreseen by this study. To the authors' knowledge, there is no data on the thickness of the periacetabular periosteum in adults. However, the thickness of the femoral periosteum is usally less than 0.2 mm and can be even thinner in elderly patients.[19] Ninety percent of the pelvises investigated in this study had contralateral differences in implant-bone distance of maximum 0.82 mm. This means that even with the potential bias of the periosteum, the differences between left and right side are most likely less than 1 mm. Further MRI-based studies may clarify the true impact of this limitation.

If done with the necessary volumetric resolution, 3D printing is costly and time-consuming. In addition, the quality of the whole process highly depends on how accurate the bending of the plates based on a template is performed. Future applications may skip the use of a 3D-printed model as a template and directly plan implants on a virtual model of the mirrored hemipelvis in order to obtain 3D-printed patients-specific implants. [9, 20] At the time being, however, the biomechanical stability of 3D printed pelvic implants is still in question.

Conclusion

With regard to the periacetabular surface of the inner pelvis, the pelvis can be considered sufficiently symmetric for using the mirrored contralateral hemipelvis as a template for patient-specific implants in acetabular fracture fixation.

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Figure legends

Figure 1 Comparing surface using a virtual reference implant

The SOMA implant fitting tool was used to optimally match the reference plate's shape with the hemipelvis' surface (A). This was repeated for the contralateral hemipelvis and the distances between reference plate and bone surface were determined (B). Then the distances were averaged for each side and the difference between these means were calculated (B+C).

Figure 2 Pairwise delta

The pairwise delta represents the median absolute difference between the right and left average bone-to-implant distances. 95% of pelves showed a surface asymmetry of less than 1.03 mm.

Figure 3 Outliers

Examples of two outliers with a greater pairwise delta than 95 % of the sample: Both show assymetric ridges or ossifications of the pecten pubis resulting in pairwise deltas of 2.79 mm (A) and 1.83 mm (B). (A) was the case with the highest pairwise delta found in the whole sample.

Figure 4 Region-specific deviations

Combined patches of distance-measures for all pelvises of the database. While the pre-shaped implant fits excellent in the in the periacetabular area, some small deviations were seen on the very anterior region of the plate.